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THE HEXATRON

A new Thumbgonimeter

By

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Interest in the study of the kinesiology of the human thumb dates back many centuries. *Galen* (a. 200 A. D.), *Winslow* (1752), *Bichat* (1802), *Duchenne* (1867), *du Bois-Raymond* (1895) and *Fick* (1911) have all contributed to information on this topic through their studies. Whereas these authors have developed the anatomic and physiologic aspects the more recent authors mainly represent clinicians—orthopaedists and hand surgeons (*Grunkorn* 1932, *Bunnell* 1938, 1956, *Goldner & Irvin* 1950, *Wheeler-Haynes* 1944, *Kaplan* 1953 and *Littler & Cooley* 1960, 1963).

The various theories proposed throughout the years have been generally based on: 1) anatomical studies, 2) electrostimulation studies (*Duchenne* 1867) and recently electromyographic techniques (*Weathersby et al.* 1963). The anatomical studies have been supplemented by observing the angular displacements following controlled tension on the isolated tendons. The registration of movements has been mainly by the visual observation of the naked thumb. In some cases this registration was facilitated by indicators placed on the thumb, eventually working against a system of scales (*Bunnell* 1956, *du Bois-Raymond* 1895). Roentgenologic registration has also been utilized (*Mannerfelt* 1964). Simple visual observation is probably the least unsatisfactory of the methods previously used, unless the purpose is to record movements in one plane, in which case x-ray photography or cinefluorography works well. Those systems which depend on indicators placed on the thumb are subject to potential sources of error due to the motion of the skin in relation to the underlying bone. There has not been described any exact method of registering the thumb movements throughout the full normal range.

One of the authors (B. E.) studied thumb kinesiology for some years. Originally a study was planned using electromyography registration of the movements such as *Long et al.* (1960, 1961, 1962) have used on the fingers. Whereas cinematography is satisfactory (in respect of reliability) when aimed at movements in one plane only (*e.g.* the hinge movements of the interphalangeal joints of the finger) this method has not proved reliable when applied to the more complex circumductory range of the thumb. Specifically, it has been impossible to determine the degree of rotation that occurs coincidentally with opposition. The use of two synchronized movie cameras or one camera connected with a system of mirrors, has been suggested but such methods are difficult and the results singularly complicated. Furthermore we feel convinced that such readings will involve considerable errors. With these considerations in mind it was tempting to apply a more advanced technology to the problem. Working a number of theoretical considerations and discussions one of the authors (C. B.) designed the apparatus to be described in the following.

Prior to the physical shaping of the goniometer the authors agreed on the following ideal requirements: The goniometer should . . .

1. permit complete and unrestricted movement of the finger examined. (This means that the apparatus has sufficient range in all directions, has no static or dynamic loading and does not exercise resistance against the movement of the thumb).
2. be simply though safely attachable to the finger examined and
3. yield good and reproducible readings.

The authors feel that the usual demand for simplicity of construction and immediate correlation of results is somewhat antiquated, and—if rigidly upheld—denies the potential application of advanced technological systems.

The apparatus is principally based on a three-dimensional linkage mechanism (shown in Figure 1) consisting in two congruent ternary links ABC and DEF and three binary links of equal length CF, BE, and AD. All joints are thought to be ball joints. In case only two of the binary links are parallel the angular orientation of the ternary links ABC and DEF. This necessary condition can be achieved by letting two of the ball joints (*e.g.* C and F) be replaced by two universal joints with parallel yokes.

By doubling the system as shown in the dotted lines in Figure 1 it is possible to have two elements ABC and GHK which are rotationally coupled, but within certain limits translationally unrestricted.

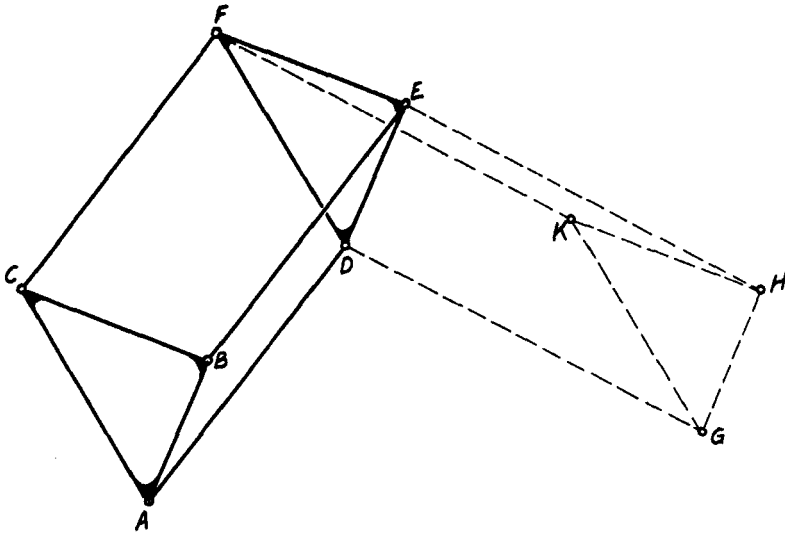


Figure 1. Simple linkage mechanism for transferring of rotation.

With few alterations the system can be recognized in Figure 2. Here (c) will make the same angular movements as (b) which again will have to follow link (a) in its rotations. Thus link (c) will follow link (a) which is attached to the thumb. Link (d) and (f) are hinged so that they will always be in a vertical plane. The angular position of this vertical plane according to the reference system (as measured with transducer 6) in connection with the horizontal angles of link (d) and (f) (from transducer 4 and 5) gives the translational position of the point (p). The angular movements of link (c) according to link (g) (the position of which is determined by transducer 4, 5, and 6) are measured by transducer 1, 2, and 3. Thus the signals from the six transducers will contain complete information about the movement of link (a), and hence about the thumb.

High precision gold wire potentiometers are used for transducers with very little frictional torque. They are placed in such a way that they tend to balance the whole system and by further addition of three balance weights the system can be brought in complete balance so that even the weight of the splint attaching the thumb with link (a) can be compensated. The dynamic loading is kept small by the application of very light materials and small dimensions. Either small single groove ball bearings or sapphires are used for pivots.

The signals are digitized and fed into a digital computer which

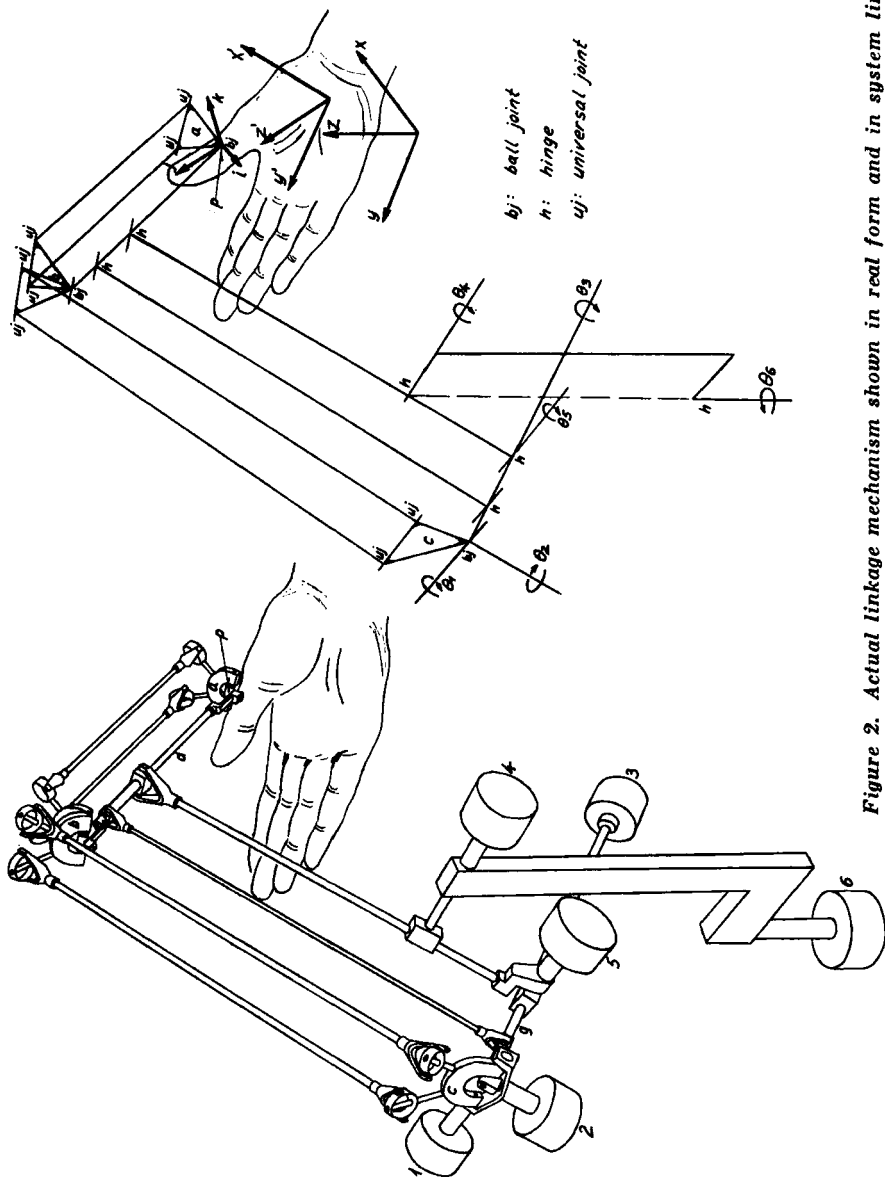


Figure 2. Actual linkage mechanism shown in real form and in system lines.

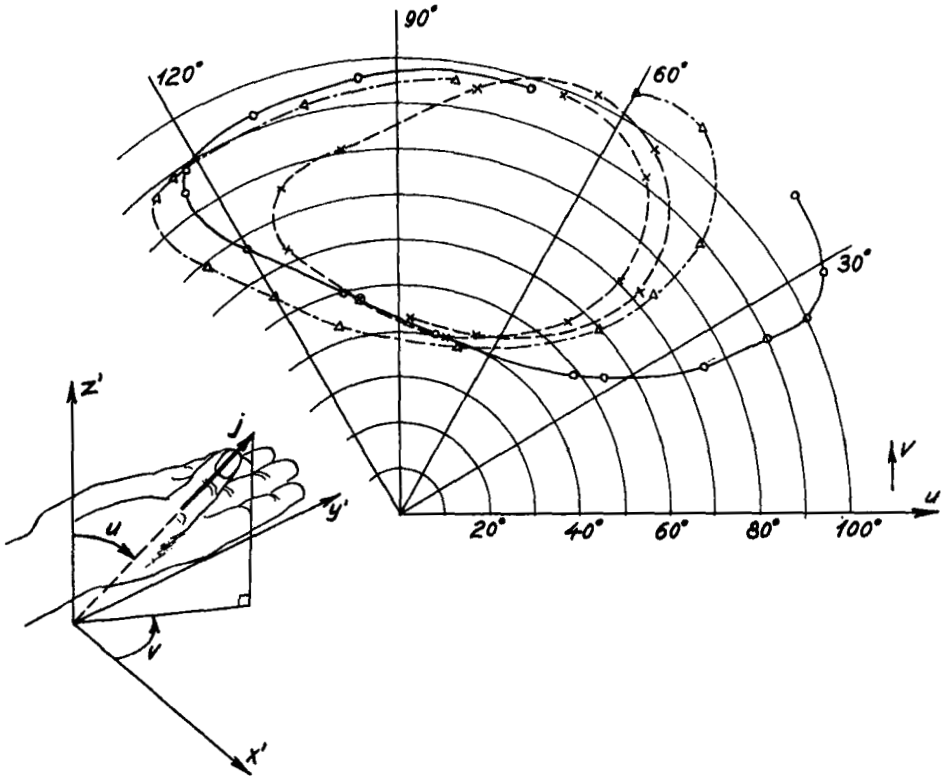


Figure 3. Maximum mobility of phalanx for three different persons. Shown in polar plot.

determines the position of the unity vectors i , j and k (connected to the fingersplint) according to the computational reference system x , y , z and afterwards transforms the results to the hand reference system x' , y' , z' . Of course the results can be presented in any desirable form.

In Figure 3 the maximum mobility of proximalis is shown for three persons. For the measurements a splint is used which allows free movement in both the carpometacarpal joint and in the metacarpophalangeal joint.

Assuming the existense of relatively fixed points between metacarpale and carpus and between metacarpale and proximalis during the movement, it is possible further to compute the positions of the metacarpale as shown in Figure 4. The validity of the assumption concerning the relatively fixed point between metacarpale and carpus

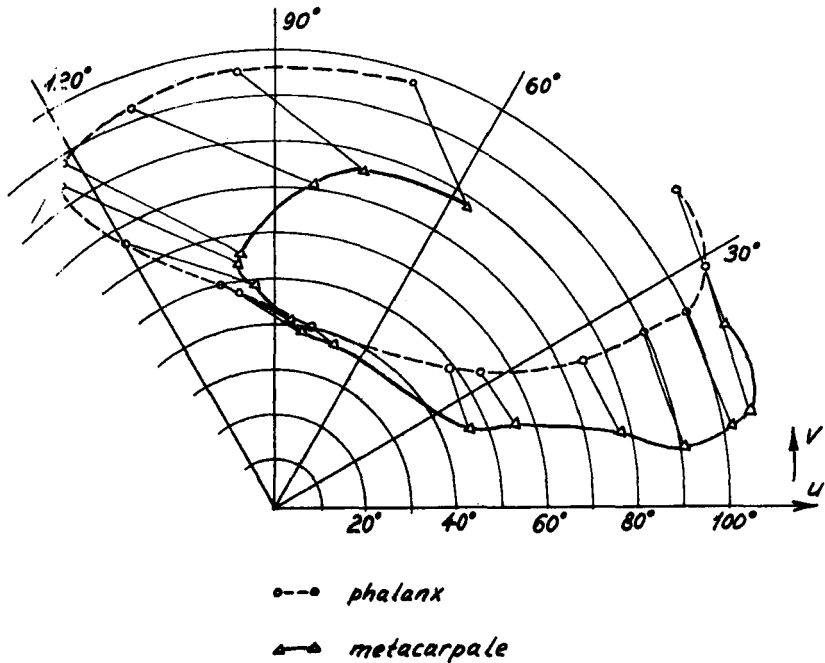


Figure 4. Measured positions of phalanx and metacarpale shown in polar plot. Points belonging together are connected.

(i.e. metacarpale having spherical motion) may be proved by applying a splint which blocks the metacarpophalangeal joint. Roentgenologic examinations have shown that it is possible to construct such a splint which with good accuracy follows the metacarpale without restricting the movement of the carpometacarpal joint.

Eventually the possibility exists of further equipping the "hexatron" with a transducer to give the movement of the interphalangeal joint. It will then be possible completely to map out the movements of the thumb bones from the "hexatron" signals.

Mechanical test procedures have shown an angular accuracy of 1° while the position of a selected point of the splint can be determined within ± 1.5 mm. This includes errors due to incorrect dimensions of the apparatus, nonlinearity of the transducers and errors from the digitizing. For a normal person the "hexatron" will not restrict the movement of the thumb. Static loading of the finger is eliminated, but at rapid movements there will be some inertia loading.

At present one of the authors (B. E.) is applying the "hexatron" at Highland View Hospital, Cleveland, for kinesiologic studies. Moreover

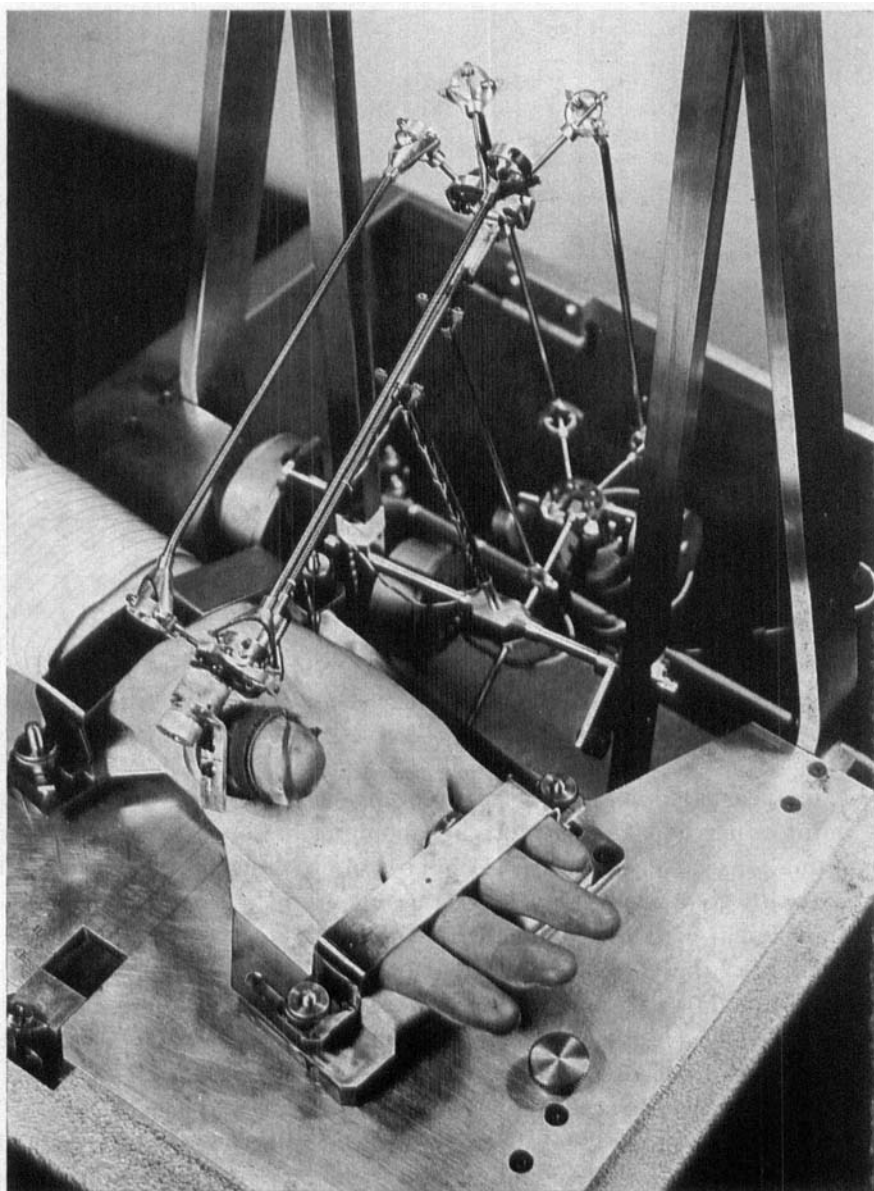


Figure 5. The HEXATRON in function.

it may be useful in the clinical examination of thumb injuries and in follow-ups after operations.

SUMMARY

The article deals with the possible methods of measuring thumb movements and describes a new goniometer which through a mechanical linkage system transfers the thumb movements to a number of transducers, the signals of which are transformed in a digital computer to give the wanted information.

The "hexatron" will allow free movement within normal range without static loading of the thumb. Angular accuracy of 1° and translational accuracy of 1.5 mm have been achieved.

RESUME

L'article traite des méthodes qui permettent de mesurer les mouvements du pouce et décrit un nouveau goniomètre qui au moyen d'un système d'enchaînement mécanique transfère les mouvements du pouce à un certain nombre de transmetteurs dont les signaux sont transformés par un "computer" digital pour donner le renseignement souhaité.

L'«hexatrone» permet les libres mouvements dans une étendue normal sans effort statique du pouce. On a obtenu une précision angulaire de 1° et une précision translationnelle de 1.5 mm.

ZUSAMMENFASSUNG

Die Arbeit befasst sich mit den möglichen Methoden zur Messung der Daumenbewegungen und beschreibt ein neues Goniometer, das mittels eines mechanischen Raumgetriebe die Daumenbewegungen auf eine Anzahl von Messwertgeber überführt, deren Signale in einem digitalen Rechenmaschine umgeformt werden, um den gewünschten Aufschluss zu geben. Das "Hexatron" gestattet freie Bewegungen innerhalb des Normalbereiches ohne statische Belastung des Daumens. Winkelgenauigkeit von 1° und translatorische Überführungsgenauigkeit von 1.5 mm wurden erzielt.

REFERENCES

- Bichat, X. (1802) *Traite d'Anatomie Descriptive*. Tome II. pp. 261-264. Paris.
Bunnell, S. ((1938) *J. Bone Jt Surg.* 20 (old series 36), 269-284.
Bunnell, S. (1956) *Surgery of the Hand*. Ed. III, pp. 41-42, 565-576. Philadelphia.

- du Bois-Reymond, R. (1895) *Arch. Anat. Physiol. phys Abt.*, pp. 433-462.
- du Bois-Reymond, R. (1896) *Anat. Anz.* 11, 464-467.
- Duchenne, G. B. (1959) *Physiologie des Mouvements*, pp. 221-227, 232-241. Transl. by E. Kaplan. Philadelphia & London.
- Fick, R. (1911) *Handbuch der Anatomie und Mechanik der Gelenke. III. Teil*, pp. 415-417. Jena.
- Galenos (1854) *Oeuvres Anatomiques, physiologiques et medicales. Tome I*, pp. 111-198. Transl. by C. Daremberg, Paris.
- Goldner, J. L. & C. E. Irwin (1950) *J. Bone Jt. Surg.* 32-A, 627-639.
- Grünkorn, J. (1932) *Z. orthop. Chir.* 57, 517-539.
- Haines, R. Wheeler (1944) *J. Anat.* 78, 44-46.
- Kaplan, E. (1954) *Bull. Hosp. Jt. Dis.* 15, 56-59.
- Kaplan, E. (1953) *Functional and Surgical Anatomy of the Hand*, pp. 6-7, 80-99, 203-211. Philadelphia.
- Littler, J. W., & S. G. E. Cooley (1963) *J. Bone Jt Surg.* 45 A, 1389-1396.
- Littler, J. W., S. G. E. Cooley (1960) *Surg. Clin. N. Amer.* 40, 259-266.
- Long, C., M. E. Brown & G. Weiss (1960) *Arch. Phys. Med. & Rehab.* 41, 175-181.
- Long, C., M. E. Brown & G. Weiss (1961) *Arch. Phys. Med. & Rehab.* 42, 559-565.
- Long, C., M. E. Brown & G. Weiss (1962) *Arch. Phys. Med. & Rehab.* 43, 450-468.
- Mannerfelt, L. (1964) Personal Communication.
- Weathersby, H. T., L. R. Sutton & V. L. Krusen (1963) *Arch. Phys. Med. & Rehab.* 44, 321-326.
- Winslow, J. B. (1752) *Exposition Anatomique de la structure du corps humain. Ed. II*, p. 349. Amsterdam.